Sedimentary Geology 294 (2013) 205–218

Contents lists available at ScienceDirect

Sedimentary Geology

journal homepage: www.elsevier.com/locate/sedgeo

Carbonate-platform scale correlation of stacked high-frequency sequences in the Arab-D reservoir, Saudi Arabia

Saad F. Al-Awwad [a,b,*], Lindsay B. Collins [b]

[a] Saudi Aramco, Dhahran, Saudi Arabia
[b] Curtin University of Technology, Perth, WA, Australia

ARTICLE INFO

Article history:
Received 15 November 2012
Received in revised form 21 May 2013
Accepted 28 May 2013
Available online 10 June 2013

Editor: B. Jones

Keywords:
High-frequency sequence correlation
Arab-D reservoir
Late Jurassic
Khurais Field
Carbonates
Reservoir quality

ABSTRACT

The Late Jurassic Arab Formation contains a number of hydrocarbon-bearing carbonates, the most important of which is the lowermost Arab-D reservoir. The reservoir lithofacies in Khurais Field are: couplets of 1) lime mud and 2) intraclastic lithofacies representing basinal turbidites; 3) pelletal lithofacies representing lower shoreface sands and silts; 4) stromatoporoid lithofacies representing a reef; 5) *Cladocoropsis* and 6) dasyclad lithofacies representing a lagoon; 7) peloidal and 8) oolitic lithofacies representing shore-attached sand sheets; 9) cryptomicrobial lithofacies representing supratidal flats; 10) anhydrites representing sabkha followed by salina deposits; and 11) stratigraphically reoccurring dolomite.

These are arranged in two, partially preserved, third-order sequences, the upper of which represents the Arab-D Member and the lower of which represents the upper Jubaila Formation. Within these sequences lie six fourth-order high frequency sequences, composed of fifth-order parasequences and parasequence-scale cycles. The preserved upward shallowing trend of the Arab-D reservoir is manifested laterally by a regional eastward thickening interpreted to be the result of an eastward progradation across the shallow Late Jurassic epeiric shelf and into the relatively deep Arabian intrashelf basin.

This study presents a correlation model that explains the drastic thickening and downward climb of the reservoir lithofacies that is observed between the outcrops south of Riyadh and the subsurface in Ghawar Field.

This model is different from the one currently used and predicts an eastward porosity improvement in the upper part of the reservoir accompanied by a porosity reduction in the lower part, assuming a null diagenetic modification effect.

1. Introduction

Predicting the existence of a facies, and harder still its extent and geometry, in the subsurface posits a defying task to the stratigrapher. This task becomes even more daunting in the realm of carbonate sequence stratigraphy owing to the in situ nature of carbonate sedimentation. The matter becomes further complicated when stratigraphic analysis is conducted in a regional, shelf-to-basin, scale since complete, shelf-to-basin, platformal transects are less common in outcrops (Goldhammer et al., 1990; Mitchum and Van Wagoner, 1991; Handford and Loucks, 1994; Tinker, 1998). Yet, regional stratigraphic analysis is key in comprehending lateral and vertical facies changes and predicting intra-reservoir geometric relationships, which together with diagenesis and fracturing shape the porosity–permeability schemes of carbonate reservoirs. Thus, platform-scaled correlation, if this could be conducted at the high-frequency-sequence scale, can contribute in resolving reservoirs' architectural heterogeneities and pin down fluid-flow patterns.

This paper presents the results of a detailed sequence stratigraphic analysis of one of the world's most prolific reservoirs, the Arab-D reservoir, in Saudi Arabia. The Arab-D is one of four carbonate reservoirs of the Upper Jurassic Arab Formation. Each of these carbonate reservoirs possesses remarkable porosity and permeability, and each is capped by a nonpermeable anhydrite unit (Fig. 1). The Arab Formation reservoirs are sandwiched between the organic-rich mudstones of the Hanifa and Tuwaiq Mountain formations below and the tight anhydrites of the Arab and Hith formations above (Fig. 1). Giant expansive structural traps, such as the anticlines of Ghawar and Khurais fields (Fig. 2), proficiently harvest the Arab Formation oils from the extensive source rocks that lay across the Arabian Peninsula. In 2009, Saudi Aramco successfully completed the largest oil expansion project in the earth's history, known as the Khurais Mega Project bringing to production nationally significant rates from Khurais and adjacent satellite fields mainly from the 100-m-thick Arab-D reservoir (Al-Ghamdi et al., 2008; Al-Mulhim et al., 2010; Mouawad, 2010).

This paper details the stratal patterns of the high-frequency sequences that compose the reservoir, discusses the sequences' characteristics and

* Corresponding author at: Curtin University of Technology, Perth WA, Australia.
E-mail address: saad.shamary@gmail.com (S.F. Al-Awwad).

0037-0738/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.sedgeo.2013.05.015

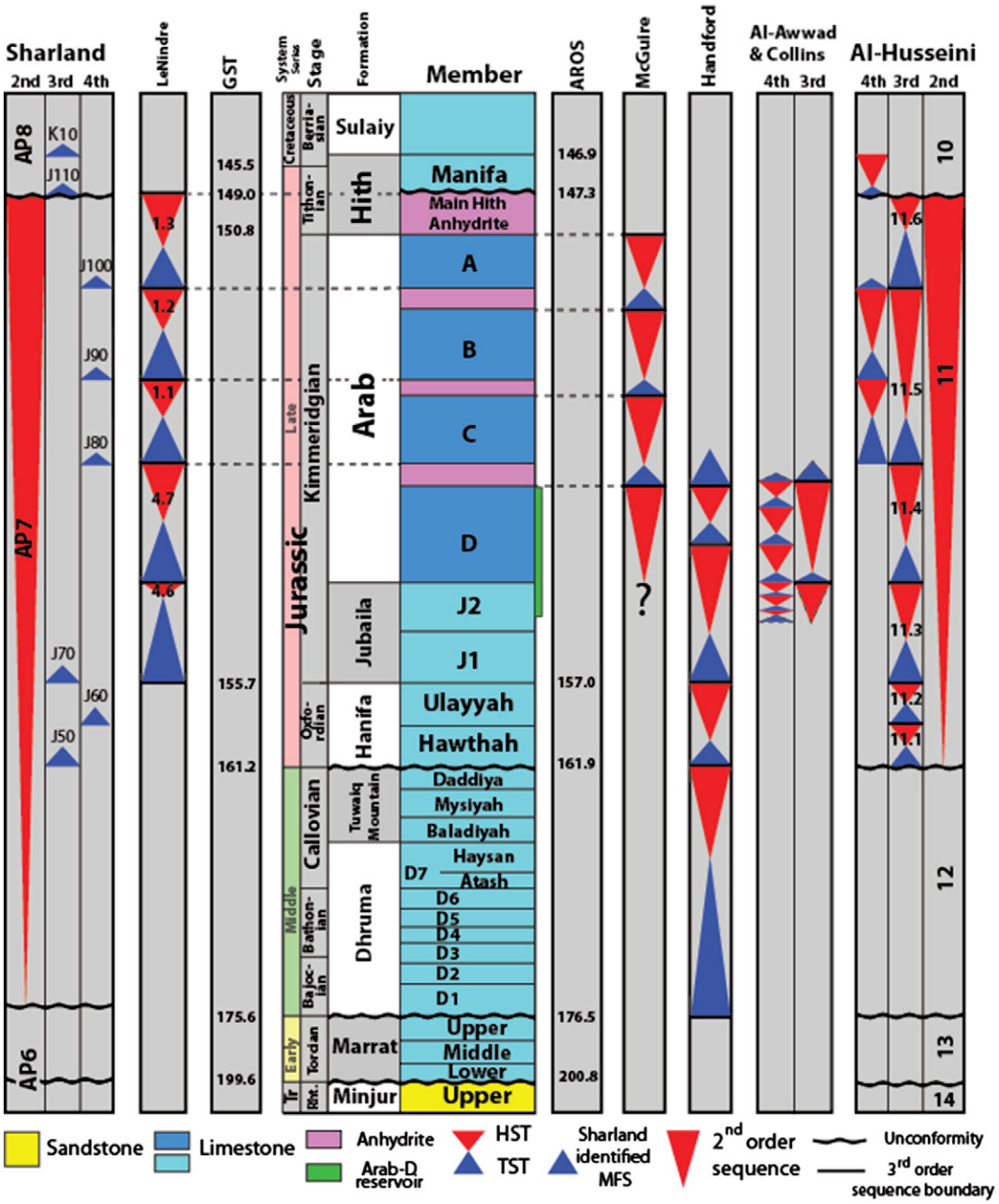

Fig. 1. Jurassic succession of Saudi Arabia. 2nd, 3rd and 4th order sequences are shown from Al-Husseini (1997, 2009) and Sharland et al. (2001). Key ages are illustrated from both the Geological Time Scale (Gradstein et al., 2004) and the Arabian Orbital Stratigraphy Project (Al-Husseini and Matthews, 2008). Lack of biostratigraphic control on the age of the Arab and Hith formations has been highlighted by Hughes (2004). Different positioning and identification criteria of HST and TST within the Arab and Hith formations are contrasted between McGuire et al. (1993), Le Nindre et al. (1990), Handford et al. (2002) and Al-Awwad and Collins (in review). Note that the Arab-D reservoir extends from the carbonates of the Arab-D Member of the Arab Formation to the upper part of Jubaila Formation. The Hellangian, Sinemurian, Pliensbachian and Alenian are not represented in Saudi Arabia's succession. The section is drawn not-to-scale to put the emphasis on the stratigraphy of the upper Jurassic.
Modified from Al-Awwad and Collins (in review), Al-Husseini (2009), Handford et al. (2002), Le Nindre et al. (1990), McGuire et al. (1993), and Sharland et al. (2001).

identification criteria and correlates them on a platform-wide, shelf-to-basin, scale. The study also addresses the long-standing controversy surrounding the progradational direction of the reservoir, which has been suggested to be prograding in virtually all directions — north, south, east and west (Mitchell et al., 1988; Meyer and Price, 1993; Al-Saad and Sadooni, 2001; Handford et al., 2002; Lindsay et al., 2006; Stephens et al., 2009). To address this controversy, the study uses an extensive, never previously used data set of 32 cored wells described meticulously at a 10-cm scale and 500 thin sections. Working at such high-resolution enables the detection of subtle lithofacies variations and deciphers what they disclose in terms of key geologic factors, their relative significance, and how they interplayed to control the paleoenvironments of deposition. The study also manifests the benefits of expanding the scope of geologic observations to a broader, trans-political-boarders sense, as it makes use of reported observation on the regional thinning and pinches out trends of the Arab and Hith formation carbonates and anhydrites in the United Arab Emirates, as discussed in Section 5.

Examining the cores from Khurais Field offered an excellent opportunity to formulate a regional perspective of the reservoir's configuration